ATTACHMENT 8: *Quality Assurance*
Hydrogeologic Characterization of the Eastern Turlock Subbasin

Quality assurance and quality control (QA/QC) policies and procedures will ensure that the technical services provided as part of this Project mitigate potential errors and adhere to high ethical, technical, and professional standards, applicable laws and regulations. QC may be defined as doing the right work the right way the first time and checking the work before release. QA is the planning and verification that ensures that QC is accomplished.

As Applicant of the Project, the City of Turlock will direct and approve preparation of a Project-specific QA/QC Plan. This Plan will provide the City, TGBA, and the State with a technically-credible hydrogeologic characterization conducted by qualified personnel, which is based on reliable data sets and information. QA/QC measures will be implemented and documented for the all stages of the Workplan including data collection, database development, data analysis and the numerical model. Requirements of the QA/QC Plan are summarized in the following sections.

8.1 QA/QC Plan

The hydrogeologic consultant for the Project will be required to develop, maintain, and adhere to QA/QC procedures for each task of the Workplan. The Project's QA/QC Plan involves data collection procedures, review of data compilation, checking and correcting data in Project databases, employing appropriate methods of data analysis, and internal review of Project deliverables. Because this Project relies on existing data, no field QA/QC measures are included. To ensure that adequate QA/QC measures are incorporated into the Project, such measures will be evaluated on three levels:

- requirement of a Project QA/QC Plan developed by the hydrogeologic consultant
- review and oversight by the Project Applicant
- review and comments on Project deliverables by the PAC

8.2 Personnel Qualifications

The QA/QC Plan will identify the qualified personnel who will be responsible for the Project. The project is a hydrogeologic characterization; at a minimum, the Project Manager and key technical personnel will be registered by the state as Professional Geologists and Certified Hydrogeologists. All aspects of the project including data collection and database development will be conducted under the direction of a Certified Hydrogeologist. In addition, the final Project report will be stamped and signed by a Certified Hydrogeologist.

8.3 Procedural Assurances

The hydrogeologic consultant will be required to include procedural assurances in the Project QA/QC Plan. Such measures will include, at a minimum, checking and verification of databases developed for the Project and a technical and editorial internal review of all project deliverables as described below.

8.3.1 Database Checking/Verification

For databases constructed for the Project, the QA/QC Plan will require a review by a qualified professional who was not involved in the database tasks. This review will include the structure of the database, the source data from which it was constructed, and spot-checking for data entry accuracy. Statistical and/or graphical analysis of certain data sets will also be employed as a QA/QC measure when appropriate. One example of such an analysis is the development of hydrographs to review water level data. Graphical methods will also be used for the well construction database such as plotting of well screens and depths. Review of a GIS map linked to the well database will provide a method of checking the reasonableness of well locations. Geochemical plotting techniques may be used to evaluate groundwater chemistry data. If laboratory analyses are sufficient, a calculation of an anion-cation balance will be conducted as a QA/QC measure of inorganic water quality data. Data that cannot be verified, but are judged to be reasonable, will be maintained in the Project database with a flag or notation regarding the nature of the data source. An example of such un-verifiable data would be results of a water quality analysis derived from a table or a report without documentation of the laboratory analysis. GIS layers constructed for the Project will contain appropriate metadata.

8.3.2 Review of Project Deliverables

The hydrogeologic consultant's QA/QC Plan will be required to include an internal review of all written deliverables by the consultant's Technical Director. The review will ensure that the data collection process, database development, and QA/QC measures are documented in the Project deliverables, as appropriate. The internal review process will also ensure a final Project report that is well-written, goal-oriented, and technically-credible.

8.4 Modeling QA/QC

The numerical model being developed for the Project is envisioned as a tool not only for this Project but for support of management activities in the future. QA/QC procedures incorporated into the modeling process are described in more detail below.

8.4.1 Use of Established Modeling Software

MODFLOW is the USGS modular finite-difference groundwater flow model, which is a computer code used to simulate three-dimensional steady-state or dynamic groundwater flow accounting for aquifer heterogeneities and multiple recharge and outflow sources. MODFLOW is fully supported by the USGS and has been extensively validated. Model validation was performed by comparing results from various model simulations of dynamic groundwater flow with known analytical solutions. MODFLOW is currently the most widely used numerical groundwater flow model in the world.

The TID MODFLOW model will be constructed and post-processed using the Groundwater Modeling System (GMS) software. GMS is a complete program for building and simulating groundwater models with MODFLOW and other groundwater model codes. The development of GMS was funded primarily by the United States Army Corps of Engineers (in partnership with the U.S. Environmental Protection Agency, U.S. Nuclear Regulatory Commission and academic partners) and is still known as the Department of Defense (DOD) GMS. GMS integrates and simplifies the process of groundwater flow modeling by bringing together sophisticated computer data management and processing tools that simplify model construction and post-processing. GMS also provides a comprehensive graphical environment for numerical modeling; tools for site characterization, model conceptualization, grid generation, and geostatistics; and sophisticated tools for graphical visualization. GMS has been peer reviewed and validated by the DOD and other federal agencies.

8.4.2 Model Calibration and Comparisons

Model calibration is the degree to which model results match actual measurements of hydraulic head or flow rate. The calibration process involves developing a hydrogeologic site conceptual model, defining model input parameter values that reflect the site conceptual model, and adjusting selected input values until the model closely matches empirical measurements. Calibration is accomplished by defining and achieving quantitative and semi-quantitative calibration goals or targets. Calibration is commonly assessed through evaluation of residuals, or the difference between observed and simulated hydraulic heads, hydraulic gradient directions, and volumetric flow rates. For the steady state site models constructed, head residuals at monitoring wells or a subset of wells are calculated, and flux residuals at model boundaries and surface features are evaluated. For the transient flow modeling, residuals were calculated in both space and time. Error residuals at each point can be averaged in a variety of ways and statistical parameters including mean error and root mean squared error can be calculated.

Comparison of calibration quality of the current USGS and TID models indicates the USGS model may more closely match observed conditions. The expanded USGS model proposed for this Project will be re-calibrated to ensure that the model closely matches observed flow conditions, especially in the Project Area along the Merced River and in the eastern portion of the basin. Calibration quality will be documented through use of hydraulic head error residuals, graphical review including scattergrams, and documentation of water budget mass balance errors. Calibration targets will be met in accordance with guidance developed by the America Society of Testing and Materials (ASTM) as described below.

8.4.3 Model Standards

ASTM guidance (ASTM D5490, 2002) provides specific methods for conducting calibration and assessing calibration quality of a numerical flow model. These ASTM guidelines will be followed and met to ensure the Project model accurately simulates groundwater flow conditions.

According to ASTM, quantitative techniques for comparing simulations to site-specific information include calculating potentiometric head residuals, assessing correlation among head residuals, and calculating flow residuals. Residuals (differences) between the computed heads and the measured heads can be defined as:

$r_i = h_i - H_i$

where:

r_i = the residual,

H_i = the measured head at point i,

h_i = the computed head at the approximate location where H_i was measured.

If the residual is positive, then the computed head was too high; if negative, the computed head was too low. Residual statistics are used to calculate the maximum and minimum residuals, a residual mean, and a second-order statistic.

The residual mean is the arithmetic mean of the residuals computed from a given simulation:

$$R = \sum_{k=1}^{n} ri \;\; / n$$

where:

R = the residual mean and

n = the number of residuals.

A second-order statistic, the standard deviation of residuals or root mean squared error (RMS), gives measures of the amount of spread of the residuals about the residual mean. The most common second-order statistic is

$$s = (\sum_{k=1}^{n} \frac{(ri - R2)}{} \; / (n-1))^{1/2}$$

where s is the standard deviation of residuals.

ASTM recommends quantitative calibration criteria for mean error and RMS: for a calibrated model, mean error should not exceed five percent of the measured hydraulic head elevation range, and RMS should not exceed 10 percent of the measured elevation range. In the Project model area, groundwater elevations are anticipated to range from about 120 to about 20 feet above mean sea level. Accordingly, the mean error and RMS for the calibrated Project model should not exceed 5 and 10 feet.

ASTM also recommends use a scattergram of computed versus measured heads to detect trends in deviations. The scattergram is produced with measured heads on the abscissa (horizontal axis) and computed heads on the ordinate (vertical axis). One point is plotted on this graph for each pair. If the points line up along a line with a zero intercept and 45° angle, then there has been a perfect match. Usually, there will be some scatter about this line, hence the name of the plot. A simulation with a small degree of scatter about this line has a better correspondence with the physical hydrogeologic system than a simulation with a large degree of scatter. In addition, plotted points in any area of the scattergram should not all be grouped above or below the line.

In addition, for the elements of the water budget that are calculated (as opposed to specified in the model input) (for example, base flow to a stream), the computed and the measured (or estimated) values will be compared. The mass balance for the simulation will be computed by comparing the sum of all inflows to the sum of all outflows and changes in storage. Differences of more than a few percent in the mass balance indicate possible numerical problems and may invalidate simulation results (ASTM, 2002).

Each of these calibration assessment methods (calibration statistics, scattergrams, and water budget errors) will be performed and documented, and calibration quality of the Project model will meet the criteria established in the ASTM guidance.

8.5 References

ASTM, 2002. Standard Guide for Comparing Ground-Water Flow Model Simulations to Site-Specific Information. Designation: D 5490 – 93 (Reapproved 2002)